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Date of Deposit

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Cedric Rodgers

Name of Person Mailing Application

Signature of Person Mailing Application

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY'S DOCKET NUMBER

TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371

SWA-02

U.S. APPLICATION NO. (if known, see 37 CFR 1.5)
Not known yet

PRIORITY DATE CLAIMED
None

INTERNATIONAL APPLICATION NO.

PCT/CA98/00921

INTERNATIONAL FILING DATE

29 September 1998

TITLE OF INVENTION

PERMANENT MAGNETIC CORE DEVICE

APPLICANT(S) FOR DO/EO/US

PIASKOWSKI, Andrew D. and GLAVAC, Vladimir

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
- ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
- ☒ This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
- ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
- ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US)
- ☒ An English language translation of the International Application (35 U.S.C. 371(c)(2)).
- ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) 35 U.S.C. 371(c)(4) and **Power of Attorney** (Executed).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 16 below concern other document(s) or information included:

11. ☐ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☐ A FIRST preliminary amendment.
 - ☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☐ A substitute specification and claims amended to conform the translated application to US practice.

US APPLICATION NO. (If known, see 32 CFR 1.5) <div style="font-size: 24pt; font-weight: bold; margin-top: 5px;">09/806067</div>	INTERNATIONAL APPLICATION NO. PCT/CA98/00921	ATTORNEYS DOCKET NUMBER SWA-02
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15. <input type="checkbox"/> A change of power of attorney and/or address letter. 16. <input checked="" type="checkbox"/> Other items or information: (a) copy of the First Page of International Publication No. WO 00/19458 (b) copy of International Search Report; (c) copies of Written Opinion and Response to Written Opinion; and (d) copy of International Preliminary Examination Report.	
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17. <input checked="" type="checkbox"/> The following fees are submitted: BASIC NATIONAL FEE (37 CFR 1.492(a)(1)-(5)): Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to UNITED STATES PATENT AND TRADEMARK OFFICE and International Search Report not prepared by the EPO or JPO \$1,000.00 International preliminary examination fee (37 CFR 1.482) not paid to UNITED STATES PATENT AND TRADEMARK OFFICE but International Search Report prepared by the EPO or JPO \$860.00 International preliminary examination fee (37 CFR 1.482) not paid to UNITED STATES PATENT AND TRADEMARK OFFICE but International Search fee (37 CFR 1.445(a)(2)) paid to UNITED STATES PATENT AND TRADEMARK OFFICE \$710.00 International preliminary examination fee paid to UNITED STATES PATENT AND TRADEMARK OFFICE (37 CFR 1.482) but all claims did not satisfy provisions of PCT Article 33(1)-(4) \$690.00 International preliminary examination fee paid to UNITED STATES PATENT AND TRADEMARK OFFICE (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(1)-(4) \$100.00 <div style="border: 1px solid black; padding: 5px; margin-top: 5px;"> ENTER APPROPRIATE BASIC FEE AMOUNT = </div> Surcharge of \$130.00 for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th colspan="2" style="text-align: left; padding: 5px;">CALCULATIONS</th> <th style="text-align: right; padding: 5px;">PTO USE ONLY</th> </tr> <tr> <td colspan="2" style="height: 150px;"></td> <td></td> </tr> </table>	CALCULATIONS		PTO USE ONLY			
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<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th style="width: 20%;">Claims</th> <th style="width: 20%;">Number Filed</th> <th style="width: 20%;">Number Extra</th> <th style="width: 40%;">Rate</th> </tr> <tr> <td>Total Claims</td> <td style="text-align: center;">20</td> <td style="text-align: center;">0</td> <td style="text-align: right;">\$18.00</td> </tr> <tr> <td>Independent Claims</td> <td style="text-align: center;">3</td> <td style="text-align: center;">0</td> <td style="text-align: right;">\$80.00</td> </tr> </table>	Claims	Number Filed	Number Extra	Rate	Total Claims	20	0	\$18.00	Independent Claims	3	0	\$80.00	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;"> MULTIPLE DEPENDENT CLAIM(S) (if applicable) </td> <td style="width: 50%; text-align: right;">\$270.00</td> </tr> <tr> <td colspan="2" style="text-align: right; padding-top: 10px;"> TOTAL OF ABOVE CALCULATIONS = </td> </tr> <tr> <td colspan="2" style="padding-top: 10px;"> <input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2. </td> </tr> <tr> <td colspan="2" style="text-align: right; padding-top: 10px;"> SUBTOTAL = </td> </tr> <tr> <td colspan="2" style="padding-top: 10px;"> Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)). </td> </tr> <tr> <td colspan="2" style="text-align: right; padding-top: 10px;"> TOTAL NATIONAL FEE = </td> </tr> <tr> <td colspan="2" style="padding-top: 10px;"> Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) \$40 per property </td> </tr> <tr> <td colspan="2" style="text-align: right; padding-top: 10px;"> TOTAL FEES ENCLOSED = </td> </tr> </table>	MULTIPLE DEPENDENT CLAIM(S) (if applicable)	\$270.00	TOTAL OF ABOVE CALCULATIONS =		<input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.		SUBTOTAL =		Processing fee of \$130.00 for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492(f)).		TOTAL NATIONAL FEE =		Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) \$40 per property		TOTAL FEES ENCLOSED =	
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US APPLICATION NO. (if known, see 37 CFR 1.5)

09/806067

INTERNATIONAL APPLICATION NO.

PCT/CA98/00921

ATTORNEYS DOCKET NUMBER

SWA-02

- a. ☒ A check in the amount of \$860.00 to cover the above fees is enclosed.
- b. ☐ Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees. A duplicate copy of this sheet is enclosed.
- c. ☒ The Commissioner is hereby authorized to charge any additional filing fees which may be required, or credit any overpayment to Deposit Account No. 15-0508. A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

OLSON & HIERL, LTD.
20 North Wacker Drive
36th Floor
Chicago, Illinois 60606

Telephone: (312) 580-1180
Customer No.: 002387



SIGNATURE

Michael A. Hierl

NAME

29,807

REGISTRATION NO.

PERMANENT MAGNETIC CORE DEVICEFIELD OF THE INVENTION

- 5 The present invention relates to the field of magnetic inductors or transformers and, in particular, relates to an inductor or transformer with a permanent magnetic core or biased core technology.

BACKGROUND OF THE INVENTION

- 10 Magnetic amplifiers have been well known in the art for use in power control systems. Magnetic amplifiers rely on the fact that magnetic fields or magnetic bias are created in the magnetic circuits of inductive power components so as to effect the control of current or power. It is known in the prior art to construct magnetic inductors containing an iron core, such as disclosed in U.S.
- 15 Patents 4,103,221 and 4,009,460, both to Fukui et al. However, when an inductor utilizes a ferromagnetic core for example, the core is readily capable of reaching magnetic saturation, due to DC electric current, resulting in a reduction of the inductance. To avoid these saturation problems, Fukui et al. proposes to utilize
- 20 permanent magnetic cores for the inductors, with such cores producing a permanent biasing magnetic field. By doing so, the core of the inductor is less likely to suffer magnetic saturation and has an extended range of useful inductance. However, the devices as described by Fukui et al. form a solid core structure, and are thus still heavy and are not well adapted for devices where a reduction of weight is critical. In addition, the devices of Fukui generally do not maintain a precise and steady
- 25 level of flux density or saturation, throughout a wide range of DC current. Furthermore, the device of Fukui are specifically designed for DC current applications, and do not appear to be effective in AC current applications.

In addition, magnetic devices such as transformers, chokes and inductors commonly used silicon grade steel for the magnetic core and copper or aluminum for the windings. Over the last decades, this technology has not progressed but improvements have been made in materials and processes for the constructions of such transformers. However, a need still remains for magnetic technology with reduced energy loss characteristics, reduced weight and lower cost. A need also exists for energy efficient and cost efficient transformers which can be utilized in high power consumption circuits, such as ballasts for street lighting and arc discharge lamp applications, or circuits used in current, power control and distribution.

SUMMARY OF THE INVENTION

It is a feature of the present invention to provide inductor devices which are highly energy efficient and produce low amounts of heat.

It is another feature of the present invention to provide inductor devices which are lightweight and compact.

It is a further feature of the present invention to provide an inductor device which can be used in a variety of different applications, such as a transformer, current controller, or as a power equipment protection device.

According to the above features, from a first broad aspect, the invention provides a permanent magnetic core device for use as a transformer, inductor, choke, or a component in a current limiting circuit,

CHARACTERIZED BY:

first and second layers of magnetic conductive material (2) retained in a predetermined, spaced apart relationship with respect to one another, so as to define opposed facing surfaces at least at first and second end portions thereof, a gap defined between said layers;

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a first permanent magnetic piece (3) located at said first end
portion between said first and second layers of ferromagnetic material, and a
5 second permanent magnetic piece (3) located at a second end portion between
said first and second layers of magnetic conductive material, the first and
second permanent magnetic pieces being placed so that their fields are additive;

coil means surrounding each of said first and second layers of
magnetic conductive material, said coil means extending within said gap
10 between said first and second permanent magnetic pieces and being placed so
that fields produced by the coil means are additive.

In accordance with a second broad aspect, the invention provides
a toroidal permanent magnetic core for use as a transformer, choke or
component in a current limiting circuit, C H A R A C T E R I Z E D B Y:

15 a first semi-circular toroidal ferromagnetic piece (6) having first
and second ends;

a second semi-circular toroidal ferromagnetic piece (6) having
first and second ends;

said first and second ends of said first toroidal ferromagnetic
20 piece being arranged to face the first and second ends of said second toroidal
ferromagnetic piece, such that the ends of said first and second toroidal pieces
are opposed and spaced apart;

permanent magnetic means (7) interposed between said ends of
said toroidal ferromagnetic pieces and joined with said toroidal ferromagnetic
25 pieces;

a coil (9) surrounding a portion of said first toroidal
ferromagnetic piece or said second toroidal ferromagnetic piece, said first and
second toroidal ferromagnetic pieces and said permanent magnetic pieces
defining a closed toroidal structure.

In accordance with a third broad aspect, the invention provides a multi-phase electrical device for use as a power distribution transformer, a power distribution protection device or a current limiting device, CHARACTERIZED BY:

a first core structure (21) and a second core structure (24), each of said first core structure and second core structure having a perimeter and at least one vertical limb extending within said perimeter of each core structure;

said first and second core structures being retained in juxtaposition by permanent magnet sets (19, 20) interposed between said first and second core structures; and

coils (18, 22, 23) surrounding at least a portion of said perimeter, and surrounding at least a portion of said at least one vertical limb;

wherein said first and second frames and permanent magnet sets form a unit.

BRIEF DESCRIPTION OF THE DRAWINGS

The preferred embodiments of the present invention will now be described with reference to the accompanying drawings in which

FIG. 1 illustrates a perspective view of the preferred magnetic core device of the present invention:

FIG. 2 illustrates geometrical parameters of the preferred magnetic core device of the present invention, which parameters are utilized in Equations 1-3, described in the Detailed Description of the Invention.

FIG. 3 illustrates a perspective view of an alternative embodiment of the magnetic core device.

FIG. 4 illustrates a second alternative embodiment of the magnetic core device.

FIG. 5 illustrates a plot of inductance versus current for the embodiment of Fig. 1 in a flux saturated condition.

FIG. 6 illustrates a plot of inductance versus current in a circuit with two magnetic core devices placed in an "Anti-Phase" connection, where the polarities of the two core devices are opposed.

FIG. 7 illustrates a plot of current versus time in a circuit where the magnetic core devices are placed in the Anti-phase connection.

FIG. 8 illustrates a schematic circuit diagram where magnetic core devices are placed in Anti-phase connection, and which produces the current waveform shown in Fig. 7.

FIG. 9 illustrates a plot of magnetic flux density over the length of the magnetic core assembly, along the line X-Y in Fig. 1, and at zero current flow.

FIG. 10 illustrates a plot of flux density over the length of the magnetic core assembly, along line X-Y in Fig. 1, and where the current running through the coils of the circuit are creating a field which opposes the field of the permanent magnets.

FIG. 11 illustrates a hysteresis curve plotting magnetic flux density versus field strength and which further illustrates the static and dynamic operating points of a saturated magnetic core device 14 of Fig. 8.

FIG. 12 illustrates a hysteresis curve plotting magnetic flux density versus field strength and which further illustrates the static and dynamic operating points of a flux saturated magnetic core device 16 of Fig. 8.

FIG. 13 illustrates an effective hysteresis curve plotting magnetic flux density versus field strength for the combined operation of the two flux saturated magnetic core devices in Fig. 8.

FIG. 14 illustrates hysteresis curves plotting magnetic flux density versus field strength for a standard inductor, choke or transformer, wherein the magnetic core device of the present invention is operated at non-flux saturated conditions.

FIG. 15 illustrates an application of a three-phase transformer in which the operating conditions of Fig. 14 are applicable.

FIG. 16 illustrates a vector diagram for showing flux vectors that would be established for an embodiment having reduced hysteresis losses.

FIG. 17 illustrates an alternate embodiment of the invention which utilizes the principles illustrated in Fig. 16.

20 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows a perspective view of a preferred embodiment of the permanent magnetic core device of the present invention. This device includes two coils 4,5 wrapped around layers of magnetically-conductive steel material 2, forming a ferromagnetic core. Permanent magnetic pieces 3 are placed at opposing ends of the assembly. However, it may be desirable in certain applications to utilize only one magnet in the magnetic core device. To couple the magnetic pieces 3 to the ferromagnetic layers 2, magnetic pole pieces 1 may be utilized in layers positioned between the magnetic pieces 3 and the ferromagnetic layers 2. The coils are _____

- 6 -

positioned between the magnetic pieces 3 and the ferromagnetic layers 2. The magnets 3 are placed in such a manner that their fields are additive. The coils are also placed so that the fields produced by the coils are additive. The present device can be utilized as a transformer, inductor, choke, or in a current limiting circuit as well. In comparison to known prior art transformers and inductors, the device of the present invention is lighter, and has lower demonstrated hysteresis losses in AC circuit application.

Theory Supporting Use Of Permanent Magnetic Core Device As Current Controller

The permanent magnetic core device of the present invention can also be utilized as a current controlling device, and this application can be theoretically demonstrated. Reference is made to Figure 2 which illustrates the various dimensions of the device in Figure 1. The thickness of the permanent magnet 3 is designated by "th". The length of the permanent magnet is illustrated by "Lm". The depth dimension of the permanent magnet is "S" and the distance of the lower surface of the magnet to the lower surface of the ferromagnetic layer 2 is designated by "P". The ferromagnetic layer 2 has a thickness "W_i", and a coil winding length "II". Accordingly, the maximum theoretical flux density of the device will be defined by:

$$(1) \quad B_{mf} = \frac{NpIs Hm th \mu_0}{\left(\frac{H Lm}{\mu_r W_i} \right) + NpIs th}$$

Where "Hm" is the magnetic field strength, "NpIs" is the number of poles, "H" is the coil winding length as illustrated in Figure 2, "th" is the magnet thickness illustrated in Figure 2, "Lm" is the length of the magnet illustrated in

Figure 2, " μ_0 " is the permeability of free space and " μ_r " is the permeability of the ferromagnetic core layers 2.

- 5 If a field is applied opposing the magnets by the coils 4 and 5 of Figure 1 of turns N , and current I , then the residual flux density in the magnets will be given by:

$$(2) \quad B_r = \frac{(N \mu_r \mu_0 H_m \cdot th - N \cdot I) \cdot \mu_0}{\left(\frac{H \cdot L_m}{\mu_r \cdot W_i} \right) + N \mu_r \cdot th}$$

10

Since the flux density in the ferromagnetic core is related to the magnetic residual flux density " B_r " by the ratio L_m/W , the ferromagnetic core saturation flux density can be approximated by:

$$15 \quad (3) \quad B_s = \frac{(N \mu_r \mu_0 H_m \cdot th - N \cdot I) \cdot \mu_0}{\left(\frac{H \cdot L_m}{\mu_r \cdot W_i} \right) + N \mu_r \cdot th} \cdot \left(\frac{L_m}{W_i} \right)$$

- If the value " B_s " is greater than the value required to saturate the core B_{sat} , then the inductance of the permanent magnetic core assembly will be minimal, as the current I in coils 4, 5 of Figure 1 is increased to the point where the core desaturates, then the inductance of the permanent magnetic core will maximize. Thus, equation (3) demonstrates that for the saturation mode of the permanent magnetic core device, this device operates as a controller of current. In AC circuits, the maximum inductance value will form a high impedance to current, while the minimal inductance will form a low impedance to current.

25

Characteristics of Permanent Magnetic Core Device

Figure 5 illustrates the variations of inductance against current on the device of Figure 1 in the magnetic flux saturated condition. As the current

changes from the negative to the positive direction, the inductance suddenly increases to a constant, steady level. With this sudden change in inductance,

5 the impedance to _____

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change in current will also increase, and thus the device will serve as a predictable controller of current.

If two of the permanent magnetic core devices of Figure 1 are joined in series together, they can produce a system which will provide excellent control over current in AC applications. Figure 8 illustrates a simple circuit diagram where two permanent magnetic core devices, such as those shown in Figure 1, are joined together with repelling poles facing each other. The transformer device in figure 15 may also be used in three phase application, whereby the characteristics shown in figure 6 would be applicable per phase. The two permanent magnetic core devices are illustrated as 14 and 16 in Figure 8, and are connected to an AC voltage source 13, a resistance load 17, and a third structure which could be, for example, a lamp or current monitoring device 15. The operating characteristics of this circuit are illustrated in Figures 6 and 7. Figure 6 illustrates changes in inductance versus current and shows the sudden increase in inductance at both negative and positive current directions. These changes in inductance translate into changes of impedance which control the current in the circuit. The actual appearance of the electrical current waveform is illustrated in Figure 7, which plots current versus time, and demonstrates that the electrical current waveform in the system of Figure 8 is nearly square. The actual "squareness" of the waveform will depend upon the geometry of the permanent magnetic core devices employed, and other geometries for the permanent magnetic core device are illustrated in Figures 3, 4 and 15, which will be discussed in more detail in a later section. Thus, the permanent magnetic core device, whether it is used alone or in a circuit with several such devices, effectively serves as a controller of current.

Figures 9 and 10 illustrate the distribution of magnetic flux across the length of the ferromagnetic core in the permanent magnetic core device of Figures 1 and 2. In Figures 9 and 10, the length dimension on the horizontal axis is the dimension H from Figure 2, shown in centimeters. The vertical axis is flux density

in Teslas. Figure 9 illustrates the condition where the core of the device is flux saturated, while Figure 10 illustrates the core of the device in a de-saturated condition. The saturated condition is created when no current flows through the device, while the desaturated condition occurs when a current opposing the magnetic field strength flows through the device.

Figures 11 and 12 illustrate the hysteresis curves which are individually created by the devices 14 and 16 respectively in Figure 8. The hysteresis curve illustrates magnetic flux density against field strength. In Figure 11, the operating point A is well into the saturation region for the core, and represents the field produced by the magnets. If the current flow in the coils aids the magnetic field of the permanent magnets, then the operating point will move towards point B. If the current flow in the coils opposes the magnetic field of the permanent magnets, then the operating point will move towards point C. Point C is in the non-saturated area of the hysteresis curve. At this point, the inductance of the permanent magnetic core device is high. In Figure 12, the operating point E represents the device 16 in its saturated condition, while points D and F show the operating point moving towards the unsaturated condition.

Figures 13 and 14 illustrate the combined hysteresis characteristics of the two permanent magnetic core devices in Figure 8, or in the alternate embodiment of Figure 15 which will be later described. The characteristics of each permanent magnetic core device are combined to produce these diagrams of effective characteristics. Figure 13 shows the combined hysteresis characteristics when the two permanent magnetic core devices are flux saturated when no current flows, while Figure 14 shows the combined characteristics in a less saturated condition. As can be readily observed from these diagrams, the combined effects of the two permanent magnetic core devices produces a hysteresis curve with an extremely narrow area. Since the area of hysteresis curve represents energy lost by the operation of the device, it can be readily seen that a circuit utilizing biased core

technology of the preferred embodiment from Figure 1 (or later described alternate embodiment of Figures 3, 4 and 15) produces energy losses that are much lower than the energy losses experienced by conventional magnetic devices. Such reductions in energy losses translate in a reduction of heat and lower operating costs when the permanent magnetic core devices are utilized in a circuit.

10 ALTERNATE EMBODIMENTS OF THE INVENTION

Figures 3 and 4 illustrate the alternative embodiments for the permanent magnetic core device. In Figure 3, the permanent magnets 7 are aligned in a plane. Surrounding the magnets are a toroidal ferromagnetic core 6 and pole pieces 8 attached to the internal and external peripheries of the ferromagnetic core 6. A coil 9 is wrapped around the ferromagnetic core 6. Figure 4 illustrates a similar device, although this embodiment does not utilize the pole pieces, and the permanent magnets are shown at 10. In this embodiment, the permanent magnets 10 are shown in parallel planes, which are at an angle to the diametric plane of the toroid. In a further alternate embodiment (not shown) the arrangement of Figure 4 is utilized, but the permanent magnets 10 are arranged in non-parallel planes.

The embodiments of Figures 3 and 4 have been found to be ideal for use as chokes, although their application in specific circuits are not limited to chokes alone. For example, the devices of Figures 3 and 4 may not be utilized as inductors or controllers of current, or transformers.

Another alternate embodiment of the invention is presented in Figure 15. Two core structures 21 and 24 are placed adjacent to one another. Magnetic assemblies are composed of magnet sets 19, 20 and pole pieces 25, and these assemblies are then sandwiched between the two core structures 21

ART 34A-131

5 and 24. Each of the six magnetic assemblies are arranged to have opposite polarity to each adjacent magnetic assembly in both horizontal and vertical directions. However, magnetic polarity may be varied according to a given application. Each of the three vertical limbs are enclosed by coils 18, 22, 23, respectively. This particular device is advantageous when used as a power distribution transformer, a power distribution protection device or a current limiting device. The basic theory behind this device has been described

10 according to Figures 5, 6, 7, 11, 12, 13 and 14. An additional discovery has been made in which we have found that if the magnetic field is established in the core which is perpendicular to the magnetic field of the permanent magnets, then the hysteresis curve for such a device will also define a smaller area than what would be observed if the perpendicular magnetic field did not exist.

15 Thus, the creation of a magnetic field in the core which is perpendicular to the field created by horizontal pairs of permanent magnets will result in a device with substantially reduced heat generation, and greater energy efficiency. The transformer device of Figure 15 may be used in three-phase applications and displays the characteristic shown in Figure 6.

20 As we described the usefulness of static magnetic biasing in reducing core losses in ferromagnetic materials, we have also set out the principle that the bias field may not be restricted to the conventional direction of flux flow, but may also be used in the "orthogonal direction". Our invention can be extended to AC orthogonal biasing in which further advantages are

25 realized in the application of power transformers.

The advantages of magnetic biasing for reducing hysteresis losses have been demonstrated in FIGS. 11, 12, 13 and 14, however, we have found that many ferromagnetic materials, including ferrites, can be biased in a multi-dimensional manner as demonstrated in Figure 16. Figure 16 illustrates a

portion of a ferromagnetic material in which several flux density vectors are imposed. The material will exhibit a maximum flux density vector in the
5 normal direction depicted by the non-linear vector B_{norm} . Another non-linear flux density vector B_{orth} may be imposed by a magnet or by a coil, resulting in an overall non-linear flux density vector B_{res_O} . Although the material may have a magnetic _____

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saturation vector of absolute value B_{norm} , the imposed orthogonal vector B_{orth} will cause a complex non-linear vector of B_{res_o} , which exceeds the saturation value.

Due to the non-linear and inter-dependant relationship of the flux vectors described above, the "box" which depicts a two and three dimensional example (Fig 16) would not in fact have straight lines, as seen in a conventional vector diagram, but would include curved lines.

The significant point of this biasing is that the effective operating flux density of a magnetic device can be raised above the normally accepted values. with the result being improved performance. Thus, the magnetic device can be constructed in a smaller size than is normally used in conventional technology. Since the magnet can be replaced by a coil, AC biasing becomes possible, allowing an orthogonal winding which comprises part of the functional windings of the device/transformer.

FIG. 17 illustrates a practical implementation of such a device. Slots 26 provide space for the windings, but are otherwise not necessary for orthogonal operation. The device shown in figure 17 includes a core which is wrapped with orthogonal windings 27, 28. The windings 27 and 28 may consist of several windings for coupled outputs. B_{norm} and B_{orth} are shown in the drawing, demonstrating orthogonal flux paths. The scalar addition of B_{norm} and B_{orth} will exceed the saturating value of flux of the material, thus exacting and emulating a transformer or magnetic device operating beyond the normal flux operating levels of the material. The net result is lower hysteresis losses and the ability to construct the effective device in smaller sizes for weight reduction.

As can be seen in figure 17, limbs 29 conduct flux between the top and bottom sections. On one set of diagonally opposite corners, flux is additive, while on the other, it is opposing. When constructing the device of figure 17, the limbs 29 are preferably formed of unequal size.

The biased magnetic core constructions described herein are not limited to the exact configurations described, but may be varied in any manner consistent with the scope of the appended claims.

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CLAIMS:

1. A permanent magnetic core device for use as a transformer, inductor, choke, or a component in a current limiting circuit, CHARACTERIZED BY:

first and second layers of magnetic conductive material (2) retained in a predetermined, spaced apart relationship with respect to one another, so as to define opposed facing surfaces, at least at first and second end portions thereof, and a gap between said layers;

a first permanent magnetic piece (3) located at said first end portion between said first and second layers of ferromagnetic material, and a second permanent magnetic piece (3) located at a second end portion between said first and second layers of magnetic conductive material, the first and second permanent magnetic pieces being placed so that their fields are additive;

coil means surrounding each of said first and second layers of magnetic conductive material, said coil means extending within said gap between said first and second permanent magnetic pieces and being placed so that fields produced by the coil means are additive.

2. The permanent magnetic core device as claimed in claim 1, wherein said coil means comprises one or more coils.

3. The permanent magnetic core device as claimed in claim 2, wherein each of said one or more coils are wrapped around said respective first and second layers of core material.

4. The permanent magnetic core device as claimed in claim 1, wherein said first and second permanent magnetic pieces (3) are supported by

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magnetic pole pieces (1) located between the first and second layers of magnetic conductive material (2) and the respective first and second permanent magnetic pieces.

5. A toroidal permanent magnetic core for use as a transformer, choke or component in a current limiting circuit, C H A R A C T E R I Z E D BY:

a first semi-circular toroidal ferromagnetic piece (6) having first and second ends;

a second semi-circular toroidal ferromagnetic piece (6) having first and second ends;

said first and second ends of said first toroidal ferromagnetic piece being arranged to face the first and second ends of said second toroidal ferromagnetic piece, such that the ends of said first and second toroidal ferromagnetic pieces are opposed and spaced apart;

permanent magnetic means (7) interposed between said ends of said toroidal ferromagnetic pieces and joined with said toroidal ferromagnetic pieces;

a coil (9) surrounding a portion of said first toroidal ferromagnetic piece or said second toroidal ferromagnetic piece, said first and second toroidal ferromagnetic pieces and said permanent magnetic pieces defining a closed toroidal structure.

6. The toroidal permanent magnetic core as claimed in claim 5, wherein said permanent magnetic means (7) comprises two spaced-apart permanent magnets.

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7. The toroidal permanent magnetic core as claimed in claim 6, wherein said spaced-apart permanent magnets (7) are arranged along a single plane.

8. The toroidal permanent magnetic core as claimed in claim 6, wherein said spaced apart permanent magnets (7) are arranged along parallel planes, and angled with respect to a diametric plane of said toroidal permanent magnetic core.

9. The toroidal permanent magnetic core as claimed in claim 6, wherein said spaced apart permanent magnets (7) are arranged along non-parallel planes.

10. The toroidal permanent magnetic core as claimed in claim 5, further including at least one pole piece (8) attached to a periphery of said first and second toroidal ferromagnetic pieces (6).

11. The toroidal permanent magnetic core as claimed in claim 5, further including a plurality of pole pieces (8) attached to a periphery of said first and second toroidal ferromagnetic pieces (6).

12. The toroidal permanent magnetic core as claimed in claim 11, wherein said toroidal permanent magnetic core includes an inner periphery and an outer periphery and said plurality of pole pieces are attached to said internal periphery and said outer periphery.

13. The toroidal permanent magnetic core as claimed in claim 5, wherein said toroidal permanent magnetic core includes an inner and outer

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periphery and said coil (9) is wrapped around portions of said inner and outer peripheries.

14. A multi-phase electrical device for use as a power distribution transformer, a power distribution protection device or a current limiting device, CHARACTERIZED BY:

a first core structure (21) and a second core structure (24), each of said first core structure and second core structure having a perimeter and at least one vertical limb extending within said perimeter of each core structure;

said first and second core structures being retained in juxtaposition by permanent magnet sets (19, 20) interposed between said first and second core structures; and

coils (18, 22, 23) surrounding at least a portion of said perimeter, and surrounding at least a portion of said at least one vertical limb;

wherein said first and second frames and permanent magnet sets form a unit.

15. The multi-phase electrical device as claimed in claim 14, wherein said magnet sets (19, 20) are sandwiched between said first and second core structures (21, 24).

16. The multi-phase electrical device as claimed in claim 14, wherein said magnet sets (19, 20) comprise a plurality of permanent magnet assemblies positioned adjacent said perimeter.

17. The multi-phase electrical device as claimed in claim 16, wherein each magnet assembly is arranged to have an opposite polarity to other adjacent magnet assemblies.

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18. A permanent magnetic core device as claimed in claim 1, wherein a first permanent magnetic core device and a second permanent magnetic core device are joined in series so that a polarity of the first permanent magnetic core device is opposite to a polarity of the second permanent magnetic core device to control alternating current (AC).

19. The multi-phase electrical device as claimed in claim 14, wherein a first magnetic field established by the coils (18, 22, 23) is orthogonal to a second field established by the permanent magnet sets (19, 20), whereby energy losses and hysteresis losses in said multi-phase electrical device are reduced.

20. The multi-phase electrical device as claimed in claim 19, wherein vectored fluxes produced by said orthogonally arranged coils (18, 22, 23) produce a net flux density that exceeds a predetermined saturation flux density of the permanent magnet sets (19, 20).

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FIGURE 1 ORTHOGONAL CONTRUCTION OF MAGNECORE ASSEMBLY

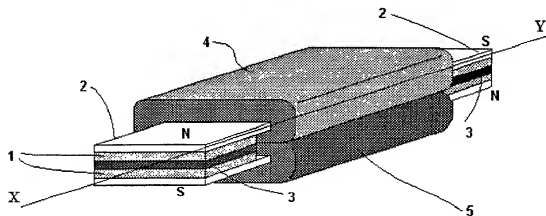


FIGURE 2 GEOMETRIC PARAMETERS OF AN ORTHOGONAL MAGNECORE ASSEMBLY

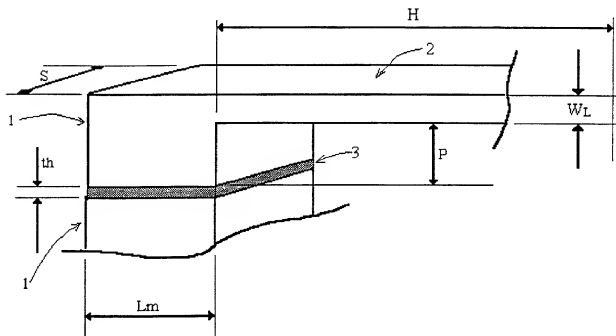


FIGURE 3 TOROIDAL FORM OF MAGNECORE WITH 2 POLE PIECES

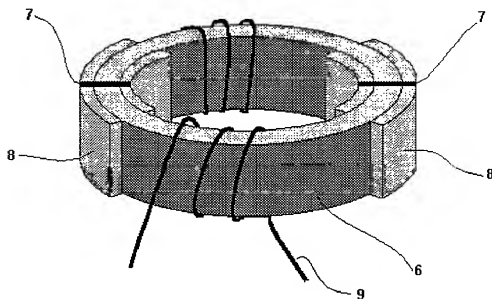
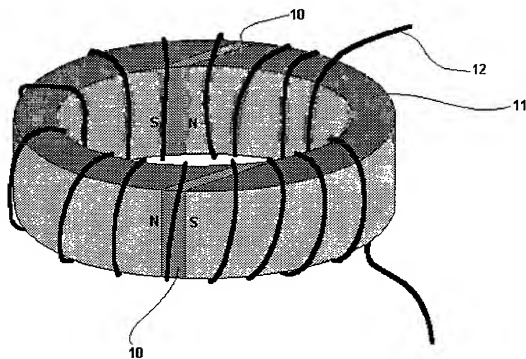
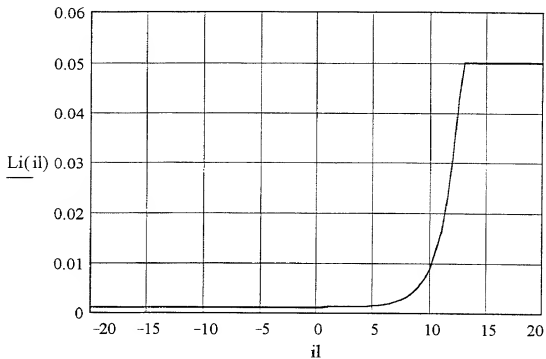
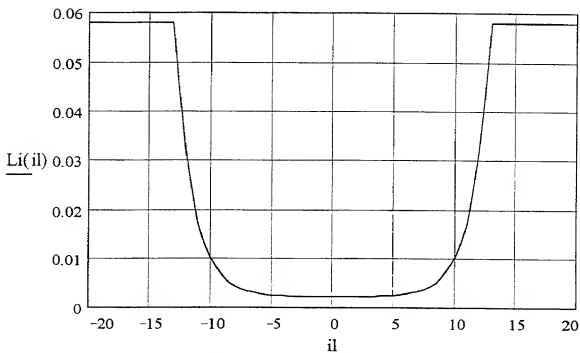


FIGURE 4 TOROIDAL FORM OF MAGNECORE WITH SKEWED MAGNETS



3/11

FIGURE 5 TYPICAL INDUCTANCE CHARACTERISTIC OF SATURATED TYPE MAGNECORE**FIGURE 6 INDUCTIVE CHARACTERISTICS OF TWO 'ANTI-PHASE' CONNECTED MAGNECORES**

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4/11

FIGURE 7 QUASI SQUARE CURRENT WAVEFORM PRODUCED WHEN MAGNECORES ARE CONNECTED AS IN FIG. 8 WITH CHARACTERISTICS OF FIG. 6

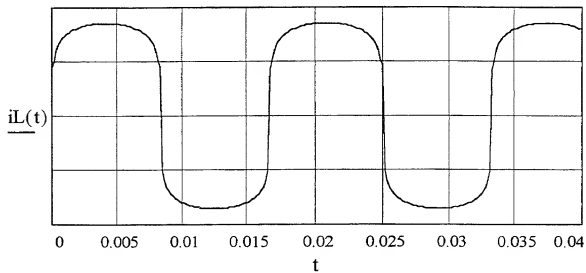
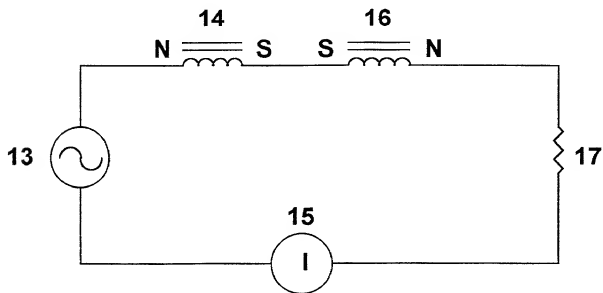
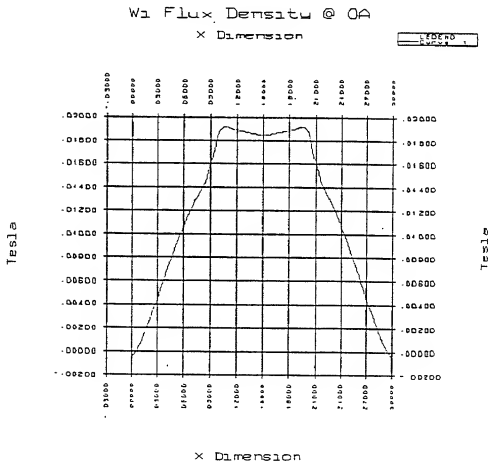


FIGURE 8 CURRENT REGULATION CONFIGURATION OF MAGNECORE ASSEMBLIES



5/11

FIGURE 9 INTERNAL FLUX DISTRIBUTION OF SATURATED
MAGNECORE DEVICE



6/11

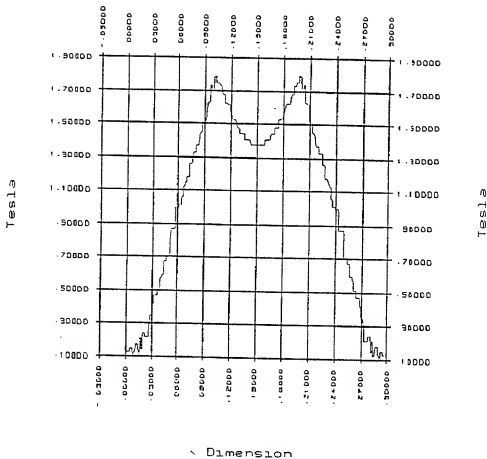
FIGURE 10

INTERNAL FLUX DISTRIBUTION OF DE-SATURATED MAGNECORE DEVICE

W1 Flux Density @ 55A

x Dimension

LEGEND
W1 Flux Density @ 55A



7/11

FIGURE 11 B-H HYSTERESIS OPERATING POINT OF FIRST MAGNECORE ASSEMBLY WHEN IN CONFIGURATION OF TWO

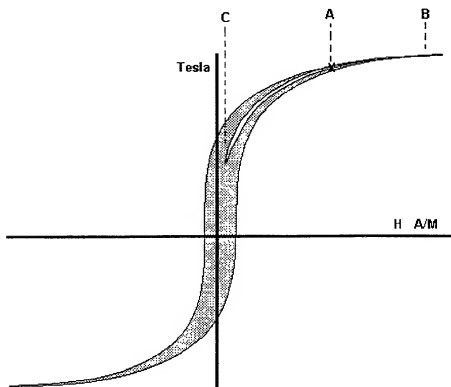
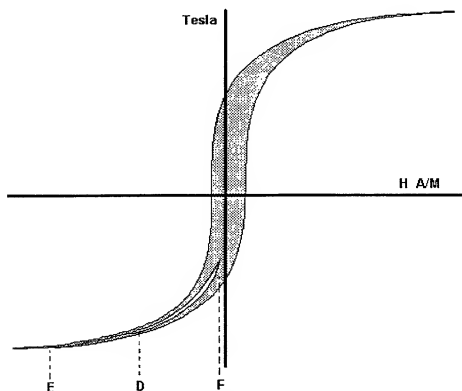


FIGURE 12 B-H HYSTERESIS OPERATING POINT OF SECOND MAGNECORE ASSEMBLY WHEN IN CONFIGURATION OF TWO



8/11

FIGURE 13 EFFECTIVE B-H CHARACTERISTIC OF A CONFIGURATION OF TWO MAGNECORE ASSEMBLIES

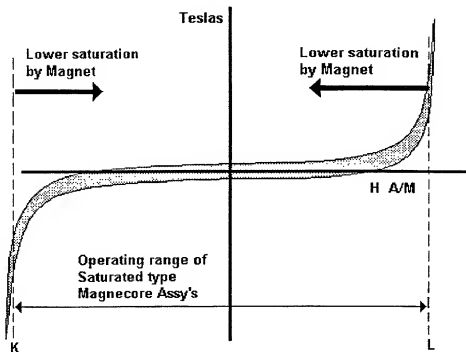


FIGURE 14 EFFECTIVE B-H CHARACTERISTIC OF DESATURATED CONFIGURATION OF TWO MAGNECORE ASSEMBLIES

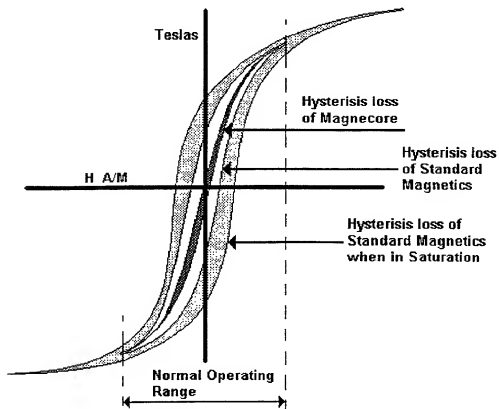
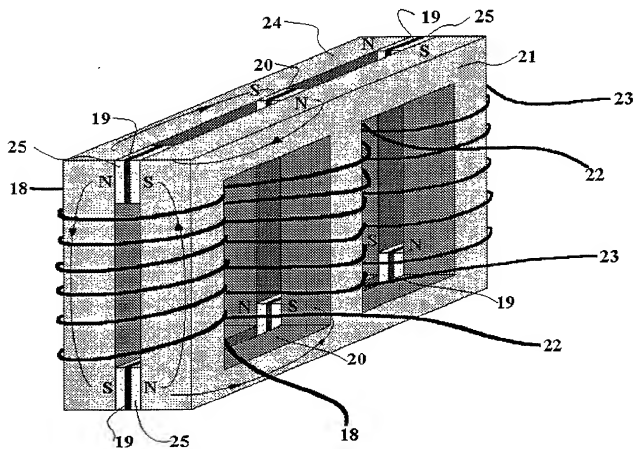


FIGURE 15 THREE-PHASE MAGNECORE CONSTRUCTION EXAMPLE



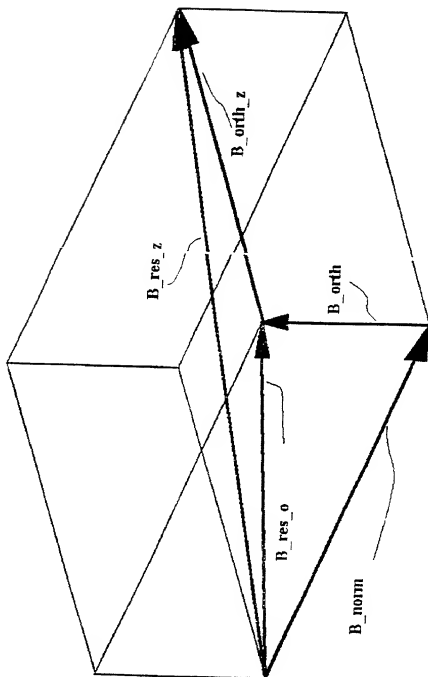


Fig. 16

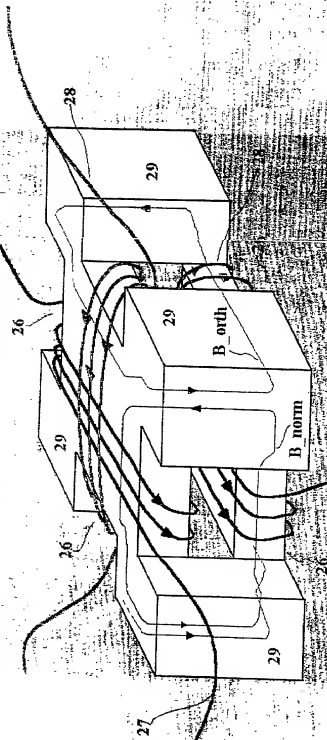


FIG. 1

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COMBINED DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63) AND POWER OF ATTORNEY	Attorney Docket Number _____ First Named Inventor <u>Andrew D. PIASKOWSK</u> <hr/> <p style="text-align: center;"><i>Complete if known</i></p> Application Number _____ Filing Date _____ Group Art Unit _____ Examiner Name _____
<input checked="" type="checkbox"/> Declaration Submitted with Initial Filing OR <input type="checkbox"/> Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16(e)) required)	

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

PERMANENT MAGNETIC CORE DEVICE

the specification of which

☐ is attached hereto.

OR

☒ was filed on September 29, 1998
(mm/dd/yyyy)

as United States Application Number or PCT International Application Number PCT/CA98/00921
and was amended on October 17, 2000 (if applicable).
(mm/dd/yyyy)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not claimed	Certified Copy Attached?	
				YES	NO
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)

☐ Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

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DECLARATION

ADDITIONAL INVENTOR(S)
Supplemental Sheet
 Page 1 of 1

Name of Additional Joint Inventor, if any:				<input type="checkbox"/> A petition has been filed for this unsigned inventor			
Given Name <u>Vladimir</u>				Family Name or Surname <u>GLAYAC</u>			
Inventor's Signature <u>Vladimir Glayac</u>				Date <u>18 March 2001</u>			
Residence: City		Pincourt <u>CA</u> State		Quebec		Country Canada	
Mailing Address		6 Racine					
Mailing Address							
City		Pincourt		Province or State Quebec		Postal Code Or Zip J7V 8G1	
Country		Canada					
Name of Additional Joint Inventor, if any:				<input type="checkbox"/> A petition has been filed for this unsigned inventor			
Given Name				Family Name or Surname			
Inventor's Signature				Date			
Residence: City		State		Country		Citizenship	
Mailing Address							
Mailing Address							
City		Province or State		Postal Code Or Zip		Country	
Name of Additional Joint Inventor, if any:				<input type="checkbox"/> A petition has been filed for this unsigned inventor			
Given Name				Family Name or Surname			
Inventor's Signature				Date			
Residence: City		State		Country		Citizenship	
Mailing Address							
Mailing Address							
City		Province or State		Postal Code Or Zip		Country	
Name of Additional Joint Inventor, if any:				<input type="checkbox"/> A petition has been filed for this unsigned inventor			
Given Name				Family Name or Surname			
Inventor's Signature				Date			
Residence: City		State		Country		Citizenship	
Mailing Address							
Mailing Address							
City		Province or State		Postal Code Or Zip		Country	
Name of Additional Joint Inventor, if any:				<input type="checkbox"/> A petition has been filed for this unsigned inventor			
Given Name				Family Name or Surname			
Inventor's Signature				Date			
Residence: City		State		Country		Citizenship	
Mailing Address							
Mailing Address							
City		Province or State		Postal Code Or Zip		Country	

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PATENT APPLICATION (37 CFR 1.63) AND POWER OF ATTORNEY**

I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

U.S. Parent Application or PCT Parent Number PCT/CA98/00921	Parent Filing Date (MM/DD/YYYY) September 29, 1998	Parent Patent Number (if applicable)
---	--	---

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As a named inventor, I hereby appoint the following registered practitioner(s) to prosecute this application and to transact all business in the Patent Trademark Office connected therewith:

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Name OLSON & HIERL
Address 20 North Wacker Drive
Address 36th Floor
City Chicago **State** Illinois **Postal Code** 60606
Country U.S.A. **Telephone** 312-589-1180 **Fax** 312-580-1189

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

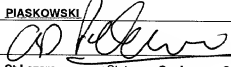
Name of sole or First Inventor:

☐ A petition has been filed for this unsigned inventor

Given Name (first and middle (if any))

Family Name or Surname

PIASKOWSKI **Andrew D.**

Inventor's Signature  **Date** 3/19/2001

Residence: City St-Lazare **State** Quebec **Country** Canada **Citizenship** Canadian

Post Office Address 535 Chaline

City St-Lazare **Province or State** Quebec **Postal Code** J7T 2B2 **Country** Canada

☒ Additional inventors are being named on the 1 supplemental Additional Inventor(s) PTO/SB/02A attached hereto.